Sudan University of Science and Technology

College of Engineering

School of Electronic Engineering

Design of an Interior Wall Painting Robot

A Research Submitted in Partial Fulfilment for the Requirements of the Degree of B.Sc. (Honors) in Electronics Engineering

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الأستهلال

قال تعالى:

"وَلَا تَمْشِ فِى ٱلْأَرْضِ مَرَحًا ۖ إِنَّكَ لَن تَخْرِقَ ٱلْأَرْضَ وَلَن تَبْلُغَ ٱلْجِبَالَ طُولًا(37)"

صدق الله العظيم

سورة الإسراء

DEDICATION

For Anas

and

To Families and Friends

ACKNOWLEDGEMENT

We give thanks to our supervisor, Dr. Ahmed Abdallah Mohammed Ali, for his advice, time and effort.

ABSTRACT

This prototype primarily addresses the design of an automatic wall painting robot. The system performs the painting process by the use of sensor information and two Arduino boards. The ultrasonic sensors mounted are on the mobile robot in a way so that the first ultrasonic sensor is positioned to give vertical coordinates while the second ultrasonic sensor gives the horizontal coordinate. Both sensor readings are fed to the arduino boards which control the base DC motors and the actuator. The actuator while extending and retracting raises the scissor lift and lowers it, respectively. The spray gun handle is mounted atop the lift, while the air compressor is set on the lower platform, and is turned ON/OFF at the bidding of the arduino board.

ABSTRACT IN ARABIC

هذا النموذج هو تصميم روبوت لطلاء الجدران الداخلية ؛النظام قادر على اداء عملية الطلاءعن طريق استخدام معلومات الحساسات و لوحين اردوينو. حساس الالتراسونيك مثبت علي الروبوت المتحرك بحيث يكون الحساس أ موضوع بحيث يعطي المسافة الرأسية, بينما الحساس ب يعطي المسافة الأفقية. قراءة كلا الحساسين تغذي الى لوحي الاردوينو اللذان يتحكمان في موتورات القاعدة و المشغل الميكانيكي. عندما يمتد و يتراجع المشغل الميكانيكي يرفع و يخفض الرافعة المقصية. مقبض مسدس الطلاء مثبت اعلى الرافعة المقصية بينما ضاغط الهواء مثبت في المنصة السفلى, ويتم تشغيله/إيقافه حسب الاشارة القادمة اليه من لوح الاردوينو.

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LIST OF SYMBOLS

B	-	Weight of Lift
d	-	Scissor Arm length
$F_{Actuator}$	-	Actuator Force
g	-	Acceleration Due to Gravity = $9.81\, m/s^2$
h_{Lift}	-	Lift's height
h_{Nozzle}	-	Nozzle's Height
h_{Base}	-	Base's Height
$h_{gun-grip}$	-	Gun grip's Height
H_y	-	Linear Load in y direction
n	-	Number of Lift's Levels
R_w	-	Wheel Radius
t_a	-	Acceleration Time
T_w	-	Wheel Torque
u	-	Horizontal Distance between the lift's arms

μ	-	Friction coefficient between the wheel and the ground
V_{max}	-	Maximum Velocity
C_{rr}	-	Coefficient of rolling resistance

ABBREVIATION

GVW	-	Gross Vehicle Weight
TTE	-	Total Tractive Effort
FA	-	force required to accelerate to maximum velocity
GR	-	force necessary to overcome Grading Resistance
RR	-	force necessary to overcome Rolling Resistance
MTT	-	Maximum Tractive Torque
RF	-	Resistance Force

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CHAPTER ONE

INTRODUCTION

1 CHAPTER ONE: INTRODUCTION

1.1 Preface

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1.4 Aim and Objectives

1.5 Thesis Outline

1.1 Preface

Fast globalization and interconnectivity create the major driving force in creating and enhancing chance. Therefore, the society must acquire new trends of innovation to prosper in their ways of life. The community has revolutionized due to the interconnectivity greatly compared to some years back when usage of technology did not exist. Saving human labor numbers and timing are only the two main advantages; besides them we must consider the opportunity to reduce or eliminate human exposure to difficult and hazardous environments, and to improve the quality of such works which would solve most of the problems connected with safety when many activities occur at the same time.

The construction industry is labor-intensive and conducted in dangerous situations; therefore, the importance of construction robotics has been realized and is grown rapidly. Applications and activities of robotics and automation in this construction industry started in the early 90's aiming to optimize equipment operations, improve safety, enhance perception of workspace and furthermore, ensure quality environment for building occupant. After this, the advances in the robotics and automation in the construction industry has grown rapidly.

Despite the advances in the robotics and its wide spreading applications, painting is also considered to be the difficult process as it also must paint the whole building. To make this work easier and safer and to reduce the number of labors automation in painting was introduced. The automation for painting the exterior wall in buildings has been proposed. Above all these the interior wall painting has shared little in research activities. The painting chemicals can cause hazards to the painters such as eye and respiratory system problems. Also, the nature of painting procedure that requires repeated work and hand rising makes it boring, time and effort consuming. These factors motivate the development of an automated robotic painting system. This project aims to develop the interior wall painting robot.

1.2 Problem Statement

Painting is often tedious, repetitive work, as well as being time-consuming work which in turn cost money. Also, workers risk exposure to harmful toxins. In addition to the fact that manual painting, paint guns and the like, depend mostly on human precision which -compared to automated spraying- lacks consistency.

The relatively narrow specimen of previously developed interior wall painting robots are found to be focusing rather of the mobility of the mechanical arm or the carrier shaft and its companion wheeled-base, instead of the actual quality of the paint spraying.

1.3 Proposed Solution

We present the automatic painting robot as a solution to the drawbacks of the traditional system.

Certain important assumptions must be taken into consideration:

That the wall to be painted is assumed to be flat and smooth, free of all obstructions. And a certain distance from side walls, ceiling and floor will not be painted; since it'll be a two DOF robot, can only paint area that require no Roll, Yaw, pitch or movement in the z-axis.

Thus, the proposed solution would be to:

First: the use of a scissor lift that provides the vertical movement. And a four-wheeled Base that provides the horizontal movement.

Second: the use of two Arduino boards with two ultrasonic sensors measuring the horizontal distance for one side wall and vertical distance from ground. These boards would, as well, control the direction and speed of the lift and turning the Spray gun ON/OFF.

1.4 Aim and Objectives

The aim of this project is to design a prototype of a wall paining robot; that paints a specified area of wall with no obstruction using a mounted spray gun.

And the main objectives are to:

- Design a wooden scissor lift with approximate maximum height of one $meter$.
- Design a one DOF base to carry the lift and remaining part
- A code controlling both lift and base (all motors) via two Arduino Uno Boards.

1.5 Thesis Outline

This research has been organized into five chapters as shown below:

Chapter two: will provide literature review of previous work on the painting robots and the tools used with it.

Chapter three: describes system design, the methodology that followed to implement this project, used tools and analysis of the system flow.

Chapter four: describes the results and the analysis of the implementation of the system.

Chapter five: the conclusion along with the recommendations and future work for this project.

CHAPTER TWO

LITERATURE REVIEW

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Background

2.2 Related Work

2.1 Background

Automation can be defined as the technology by which a process or procedure is performed without human assistance. The term was inspired by the earlier word automatic (coming from automaton), was not widely used before 1947, when Ford established an automation department. It was during this time that industry was rapidly adopting feedback controllers, which were introduced in the 1930s.

Automation has been achieved by various means including mechanical, hydraulic, pneumatic, electrical, electronic devices and computers, usually in combination. Complicated systems, such as modern factories, airplanes and ships typically use all these combined techniques. The benefit of automation includes labor savings, savings in electricity costs, savings in material costs, and improvements to quality, accuracy and precision.

Spraying paint with compressed air can be traced back to its use on the Southern Pacific Railway in the early 1880s in 1887 Joseph Binks, the maintenance supervisor at Chicago's Marshall Field's Wholesale Store developed a hand pumped cold-water paint spraying machine to apply whitewash to the subbasement walls of the store. Francis Davis Millet, the decorations director for the World's Columbian Exposition in Chicago in 1893, used Binks and his spray painting system to apply whitewash consisting of a mix of oil and white lead to the buildings at the Exposition, taking considerably less time than traditional brush painting and turning it into what has been called the White City. In 1949, Edward Seymour developed a type of spray painting, aerosol paint that could be delivered via a compressed aerosol in a can.

Spray painting is a painting technique where a device sprays a coating (paint, ink, varnish, etc.) through the air onto a surface. The most common types employ compressed gas—usually air—to atomize and direct the paint particles. Spray guns evolved from airbrushes, and the two are usually distinguished by their size and the size of the spray pattern they produce. Airbrushes are hand-held and used instead of a brush for detailed work such as photo retouching, painting nails or fine art. Air gun spraying uses equipment that is generally larger. It is typically used for covering large surfaces with an even coating of liquid. Spray guns can be either automated or hand-held and have interchangeable heads to allow for different spray patterns. Single color aerosol paint cans are portable and easy to store.

The process of air gun spraying occurs when paint is applied to an object using an air-pressurized spray gun. The air gun has a nozzle, paint basin, and air compressor. When the trigger is pressed the paint mixes with the compressed air stream and is released in a fine spray. There are two types of air-gun spraying processes. In a manual operation method, the air-gun sprayer is held by a skilled operator, about six to ten inches (15–25 cm) from the object, and moved back and forth over the surface, each stroke overlapping the before ensuring a continuous coat. In an automatic process the gun head is attached to a mounting block and delivers the stream of paint from that position. The object being painted is usually placed on rollers or a turntable to ensure overall equal coverage of all sides.

The spray nozzle is a precision device that facilitates dispersion of liquid into a spray. Nozzles are used for three purposes: to distribute a liquid over an area, to increase liquid surface area, and create impact force on a solid surface. A wide variety of spray nozzle applications use several spray characteristics to describe the spray.

Spray Patterns:

Due to a wide range of nozzle shapes and sizes, the consistency of the paint can be varied. The shape of the work piece and the desired paint consistency and pattern are important factors when choosing a nozzle. The three most common nozzles are the full cone, hollow cone, and flat stream. As shown below.

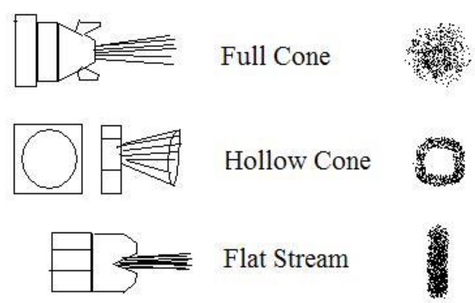

Figure 2-1 The Most Common Types of Nozzles

An Example of a Previously Implemented Painting System:

This system is for an Automatic Wall painting, writing, drawing and crack detection [12]. The major parts used in this prototype are PIC (16F877A), L293D motor drivers, DC motors. The process is carried out using the robot arm. The motor parts in the arm enable the robot to rotate in the desired directions, microcontroller programming is done to drive the motor. Infra-Red sensors are used to detect the crack in the wall during painting.

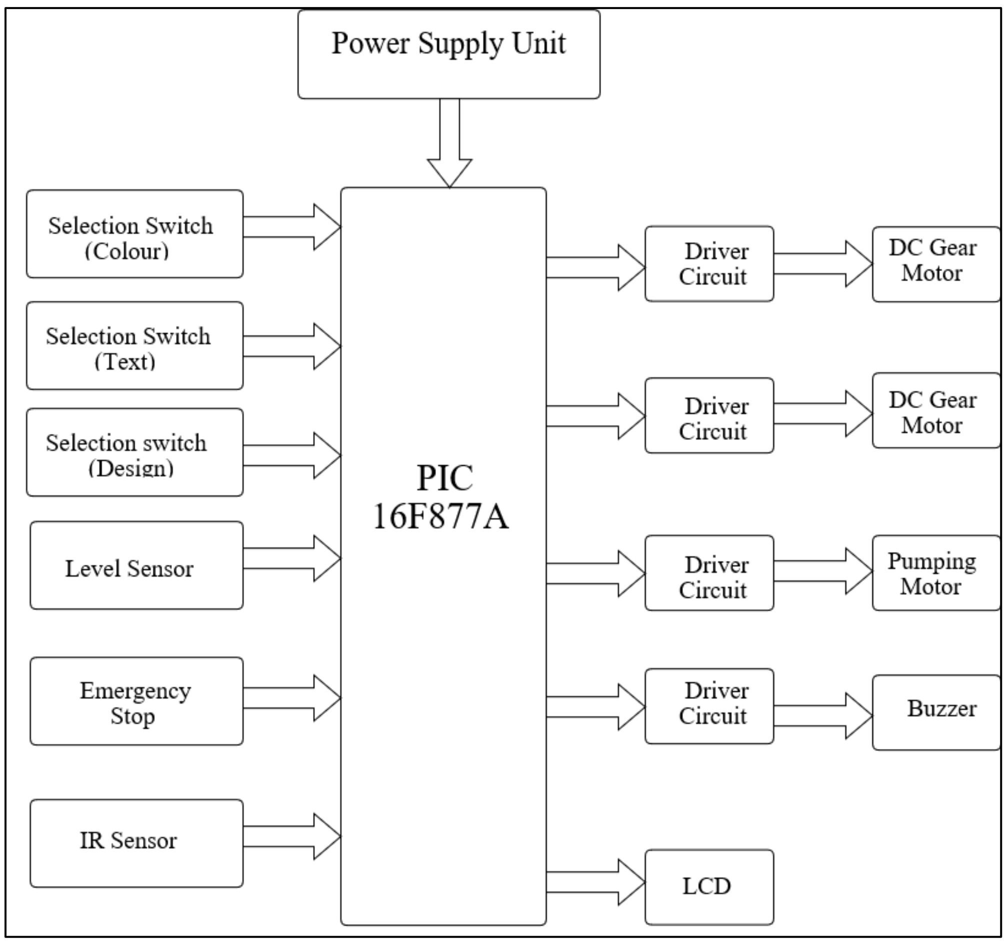

Figure 2-2 An example of Painting System Block Diagram

2.2 Related Work

The literature review detailed in this section was conducted to ascertain and understand the successes and failures of wall painting systems that have been designed before.

Warszawsky [1] and Kahane [5], developed a robot for interior finishing tasks named "TAMIR", and was used in four interior finishing tasks namely; painting, plastering, tiling and masonry. The robot has six DOF (Degrees of Freedom) with an average reach of 1.7m and end effector payload of 30 kg. It is mounted on three wheeled mobile robot which gives another three DOF. The platform moves between workstations and at each one it deploys four stabilizing legs. The robot arm used is the S-700 model made by General Motors, of 500 Kg weight. Also, a methodology for human-robot integration in construction site has been developed claimed to be profitable of introducing robots in finishing tasks with promising numbers. In case of wall painting, a reduction in total painting time of about 70% was reached, and can be increased by up to 20% if additionally ceil painting is involved. But the implemented robot can't be used in residential buildings due to its heavy weight that is over 500 kg.

In other aspects other than painting TAMIR was tested also in the execution of other tasks like plastering, about which there is however less information available. The main purpose of these experiments related to the necessity to develop highly autonomous machines for building sites: even if that problem is not completely solved, however first good results have been obtained, which perorate the feasibility of this technique. All these experiments follow the approach of testing human ergonomics prototypes. At the same time, another school of thought is working on miniature robots, which can be used for several purposes. Some of them are climb and diagnostic [2]; climbing robot for curtain wall for miniature navigation [3]. These robots have been developed because they are more lightweight and move at high speed, thus allowing operations that would be very cumbersome, and sometimes impossible heavy and slow automatic machines. Among the wide variety of applications where they can be used, there is also the possibility to adopt them in construction: they could be used to access high rise building walls or dangerous environments and perform many operations, including wall painting. They can constitute also one valid alternative to the painting robots thus far presented, because their lightness enables them to quickly move throughout every job site, despite the presence of obstacles or other operators.

For the painting container Terje Velde developed a device for automatic spray application of paint [4]. The principle was that a device is disclosed for the automatic spray application of paint. The device has a paint container and a spray nozzle arranged in close connection and adapted to provide paint from the container to the spray nozzle during the spray application. A dosing apparatus regulates the compression of an external surface against the inner volume of the paint container and thereby forces paint out of the container and into the spray nozzle through an opening of the container. Several receiving members are adapted to receive and hold the paint container close to the spray nozzle, such that the paint container is detachable and removable from the device when replacing a paint container. The paint container has an elongated feeding tube, at its opening that is held by the receiving members when the tube is inserted in the nozzle.

A full-scale mechanism for ceil painting was introduced by Aris [6]. It had three DOF without considering those of the platform, a working envelope of (84cm * 72 cm * 122 cm). Significant improvement in painting time and cost had been reached where 46 m of ceil were painted in three hours and half an hour which is 1.5 times faster than manual painting. But the robot was huge, has small work space and paints only the ceiling.

A scaled down robot setup for interior wall painting together with a multicolor spraying end tool were implemented by Naticchia [7], [8], [9] and claimed to work in full scale without reduction in performance. The robot named “Pollock#1” had six DOF, a nominal reach of 0.4 m and a maximum payload of 4kg. It should be fixed on a two DOF hexapod for horizontal movement but was not actually used in experiments. But the spray painting used will result in increased system weight which will impair the system portability.

Mohamed T. Sorour, Mohamed A. Abdellatif developed a roller-based interior wall painting robot [10]. The robot consists of a painting arm with an end effector roller that scans the walls vertically and a mobile platform to give horizontal feed to paint the whole area of the wall. The painting arm has a planar two link mechanism with two joints. Joints are driven from a stepping motor through a ball screw-nut mechanism. Four ultrasonic sensors are attached to the mobile platform and used to maintain a certain distance from the facing wall and to avoid collision with side walls. When settled on adjusted distance from the wall, the controller starts the painting process autonomously. An algorithm for automating the process of painting a single wall was developed. The implemented mobile platform was tested and succeeded in carrying the intended load while enabling the plane degrees of freedom. The two-link manipulator was tested and fulfilling the intended reachability, while maintaining low levels of vibration and noise. Overall system has been successfully integrated and tested.

P. Keerthanaa & K. Jeevitha aimed to design, develop and implement a simple automatic wall painting robot [11]. The robot was made of steel mobile platform and using conveyor shaft, spray gun & a controller unit that controls the entire operation of the robot. The system operated pneumatically so it needed an air tank or a compressor. Eventually the robot could perform painting for given dimensions of the wall using IR transmitter & receiver to detect the wall. But the pitfall was that the robot continued painting even after the wall ended.

B. Kayalvizhi, V. Seetha, B. Lavanya P. ParuthiIlamvazhuthi developed a robot for automatic wall painting, writing, drawing and crack detection [12]. The robot is mounted on equipment which permits it to move up and down, left and right along the exterior walls of a building. It is also equipped with sensors which measure indentations and protrusions in the wall surface and making it possible for painting. IR is used to enhance the current approach to detect cracks on the wall and gives indication such that we can rectify in prior from elongation of damage.

CHAPTER THREE

METHODOLOGY

3 CHAPTER THREE: METHODOLOGY

3.1 Overview

3.2 System Block Diagram

3.3 Mathematical Analysis

3.4 System Components and Circuit Diagram

3.5 System Flow Chart

3.6 Software Tools

3.1 Overview

This Chapter provides a block diagram of the system, analyses the mathematical requirement, enumerate the system's components, demonstrate the circuit diagram and the code's flow chart.

3.2 System Block Diagram

The two Arduino boards exchange information back and forth. Arduino-1 makes decisions to turn the wheels in either direction based on the reading of Sensor_A, while Arduino-2 makes decisions to extend or retract the actuator and turning the spray gun on and off based on the reading of Sensor_B.

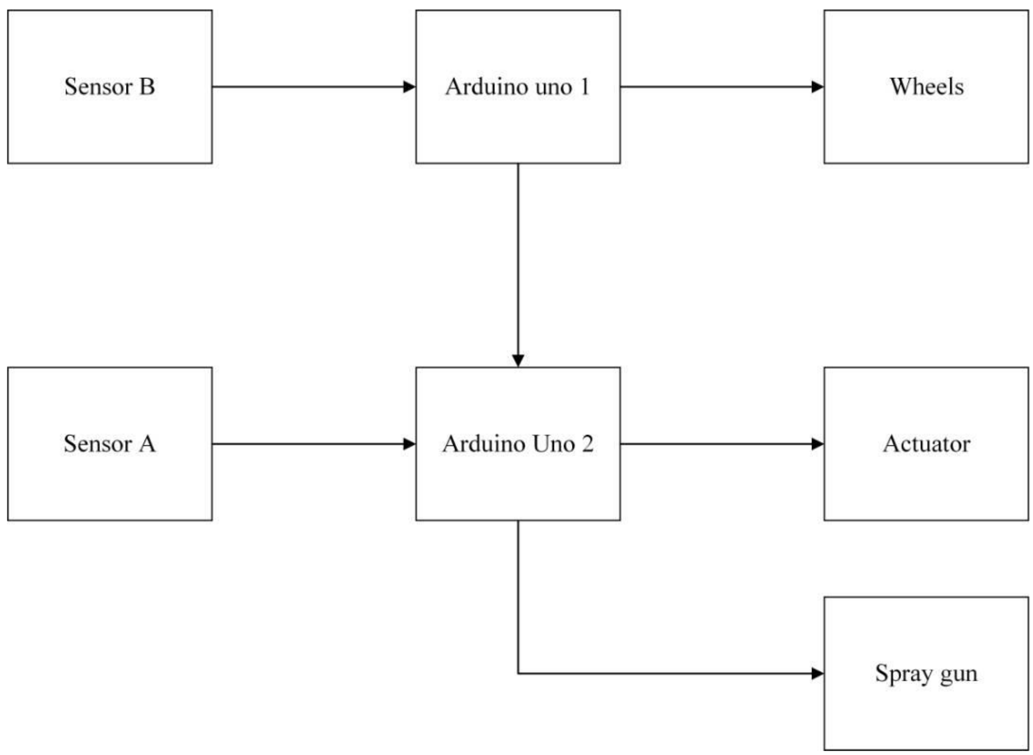

Figure 3-1 System Block Diagram

3.3 Platform Design

3.3.1 Scissor Lift

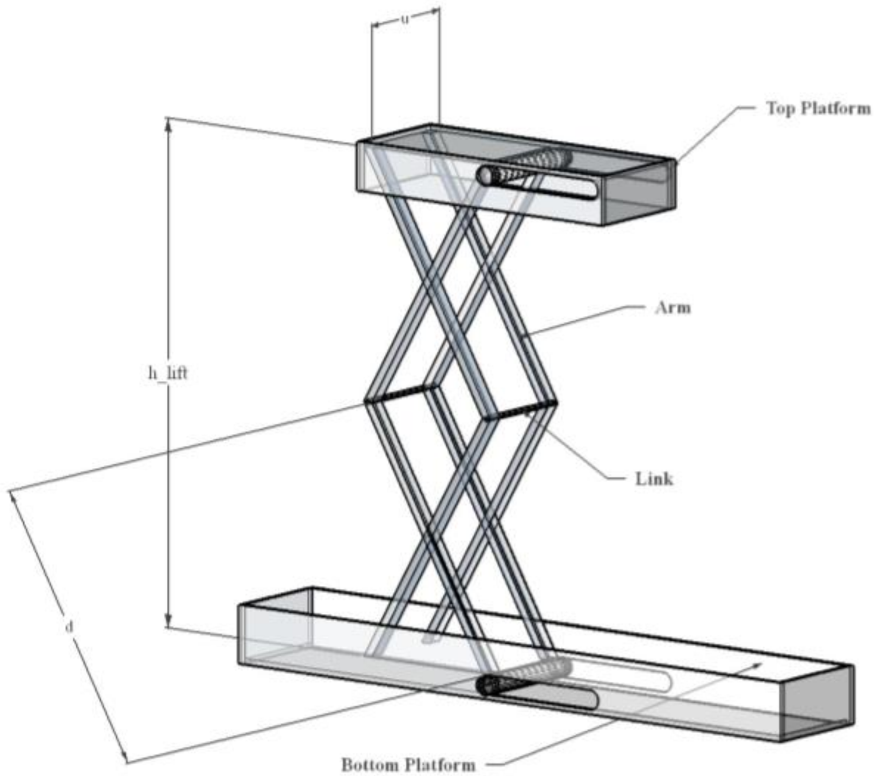

Figure 3-2 Scissor Lift

The height of the lift at any given position can be calculated using the Pythagorean theorem.

$$d^2 = \left(\frac{h_{Lift}}{2}\right)^2 + u^2 \quad (1)$$

Which is the vertical distance the lift will cover. The position of the nozzle depends on the position of the actuator (which causes an angle θ = 10° up to θ = 60°) plus the height of base and the gun grip.

$$h_{Lift} = 2\sqrt{d^2 - u^2} = 2\, d \sin(\theta) \qquad (2)$$

$$h_{Lift} = \begin{cases} 2\sin(60°) = 103.92\ cm \\ 2\sin(10°) = 20.84\ cm \end{cases}$$

$$\begin{aligned} h_{Base} &= Wheel\ Height + bottom\ platform\ Height \\ &= 6.8 + 2.54 = 9.34cm \end{aligned} \qquad (3)$$

$$h_{gun-grip} = 16cm$$

$$h_{Nozzle} = h_{Lift} + h_{Base} + h_{gun-grip} \qquad (4)$$

$$\therefore\ h_{Nozzle} = \begin{cases} 103.92 + 9.36 + 16 = 129.28cm \\ 20.84 + 9.36 + 16 = 46.2cm \end{cases}$$

Lift's Nominal Mass:

The material used is Beech Pine Wood, which has a cubic meter mass of $500\, kg/m^3$.

$$Mass\ of\ Object = Volume * Unit\ Mass\ of\ Material \quad (5)$$

- Mass atop the Lift:

$$Nozzle's\ weight + 800ml\ of\ paint \cong 1\ kg$$

- Top Platform:

$$(2.54 * 20 * 22) + (2.54 * 40 * 17) = 2844.8cm^3$$

$$mass = 3352.8 * 10^{-6} * 500\ kg/m^3 = 1.4224kg$$

- Scissor's Arms:

$$(60 * 5.08 * 2.54) * Number\ of\ Arms = 774.192\ cm^3 * 8 = 6193.536\ cm^3$$

$$mass = 6193.536 * 10^{-6} * 500\ kg/m^3 = 3.097kg$$

- Scissor's Links:

$$2(22 * \pi * 1^2) = 138.23cm^3$$

$$mass = 138.23 * 10^{-6} * 500\ kg/m^3 = 0.069kg$$

- Bottom Platform:

$$(135 * 22 * 2.54) - (30 * 2.54 * 2.54) = 7350.252cm^3$$

$$mass = 7350.252 * 10^{-6} * 500\ kg/m^3 = 3.675kg$$

$$\therefore Lift's\ Nominal\ Mass$$

$$= 0.5 + 1.4224 + 3.097 + 0.067 + 3.675$$

$$= 8.7614kg$$

3.3.2 Actuator Force

There are two ways of calculating the actuator force required to raise the scissor lift. The first method is to use the static equilibrium equations. The problem with this method is that for most actuator placements a set of at least 5 simultaneous equations result, this method is, therefore, not recommended. The second method is to use the principle of conservation of energy. In this method, frictional forces are assumed to be zero, requiring that work in equals work out (all force exerted by the actuator would result in an upward movement). [13]

Applying the same principle of conservation of energy on our scissor lift.

In our design, the lift is on a horizontal surface, so that the weight of the lift has only a y component, B_y.

$$F_{Actuator} = \left(H_y + \frac{B_y}{2}\right) \frac{n}{\tan\theta} \qquad (6)$$

At θ = 60°

$$F_{Actuator} = \left(1 * 9.81 + \frac{8.7614 * 9.81}{2}\right)\frac{2}{\tan(60°)}$$

$$\cong 60.95N$$

At θ = 10°

$$F_{Actuator} = \left(1 * 9.81 + \frac{8.7614 * 9.81}{2}\right)\frac{2}{\tan(10°)}$$

$$\cong 598.7N$$

∴ obtain an actuator with force no less than $598.7N$

3.3.3 Wheels Drive Motors

When selecting drive wheel motors for mobile vehicles, several factors must be considered to determine the maximum torque required.

The following is our design criteria:

- GVW = The Weight of (Lift + Actuator + DC Motors + Wheels + 800ml of paint + the spray gun)

Table 3-1 Masses of Major Components

Item	Mass (kg)
Scissor Lift	8.7614
Actuator	1.7
Spray gun with its compressor and 800ml of paint	2.94
4 DC Motors	1
4 Wheels	0.69
Electronics	1
Summation	16.09

$$\therefore \text{GVW} = 16.09 * 9.81 = 157.8566N$$

- Weight on Each Wheel (WW): $39.464N$
- Radius of Wheel (Rw): $3.4\ cm$
- Desired Top Speed (Vmax): $262cm/30sec \quad \rightarrow \quad 8.733cm/sec$
- Desired Acceleration Time (ta): $1\ sec$
- Maximum Incline Angle φ: $Zero$
- Worst Working Surface: Asphalt (poor)

Total Tractive Effort (TTE):

$$TTE = RR + GR + FA \tag{7}$$

Since our robot is on a horizontal surface, it has a Grade Resistance (GR) of Zero.

$$RR = GVW * \ C_{rr} \tag{8}$$

Table 3-2 Rolling Resistance For Rubber Wheels

Contact Surface	$\boldsymbol{C_{rr}}$
Concrete (good / fair / poor)	.010 / .015 /.020
Asphalt (good / fair / poor)	.012 / .017 / .022
Wood (dry/dusty/wet)	.010 / .005 / .001
Snow (2 inch / 4 inch)	.025 / .037
Dirt (smooth / sandy)	.025 / .037
Mud (firm / medium / soft)	.037 / .090 / .150
Grass (firm / soft)	.055 / .075

$$\therefore RR = 157.8566 * 0.022 = 3.473N$$

$$FA = \frac{GVW * V_{max}}{g * t_a} \tag{9}$$

$$\therefore$$

$$FA = \frac{157.8566 * 0.8733}{9.81 * 1} = 14.05N$$

$$\therefore TTE = 3.473 + 14.05 = 17.526N$$

To verify the vehicle will perform as designed regarding tractive effort and acceleration, it is necessary to calculate the required wheel torque (T_w) based on the tractive effort.

$$T_w = TTE * R_w * RF \tag{10}$$

The “resistance factor” accounts for the frictional losses between the caster wheels and their axles and the drag on the motor bearings. Typical values range between 1.1 and 1.15 (or 10 to 15%).

$$T_w = 17.526 * 3.4 * 10^{-2} * 1.15 = 0.685N.m$$

The Wheel Torque T_w is the total wheel torque. This quantity does not change with the number of drive wheels. The sum of the individual drive motor torques (see Motor Specifications) must be greater than or equal to the computed Wheel Torque.

The maximum tractive torque (MTT) a wheel can transmit is equal to the normal load times the friction coefficient between the wheel and the ground times the radius of the drive wheel.

$$MTT = WW * \mu * R_w \tag{11}$$

μ is usually 0.4

$$MTT = 39.464 * 0.4 * 3.4 * 10^{-2} = 0.54 N.m$$

The Maximum Tractive Torque represents the maximum amount of torque that can be applied before slipping occurs for each drive wheel. The total wheel torque must be less than the sum of the Maximum Tractive Torques for all drive wheels or slipping will occur.

3.4 System Components and Circuit Diagram:

3.4.1 System Components

1) 2 Arduino Uno Boards.

2) 2 Arduino's power supplies (5v, 500mA).

3) 2 ultrasonic Sensors.

The Ultrasonic sensor module is a convenient way for measuring distances from objects. This module has a lot of applications such as parking sensors, obstacle and terrain monitoring systems, industrial distance measurements, etc. It has a stable performance and high accuracy ranging.

Specifications:

- Model: HC-SR04.
- Working Voltage: 5V DC.
- Working Current: 15mA.
- Static Current: Less than 2mA.
- Output Signal: Electric Frequency signal, high level 5V, low level 0V.
- Sensor angle: not more than 15 degrees.
- Detection Distance: 2cm to 450cm.
- High Precision: Up to 3mm.
- Mode of Connection: VCC / Trig / Echo / GND.
- Adopt I/O trigger through supplying at least 10μs sequence of high level signal.
- Dimensions: 1.77in x 0.79in x 0.51in (4.5cm x 2.0cm x 1.3cm).
- Weight: 10g.

Working principle:

The module sends an ultrasonic signal, eight pulses of 40kHz square wave from the transmitter; the echo is then picked up by the receiver and outputs a waveform with a period proportional to the distance. The connected microcontroller accepts the signal and performs necessary processing.

The first ultrasonic sensor, SensorA, is positioned horizontally on the lower platform with its beam reflecting off the top platform.

The second ultrasonic sensor, SensorB, is positioned vertically on the edge of the lower platform with its beam reflecting off the wall on the right.

4) Linear Actuator (DC Motor).

Figure 3-3 Linear Actuator

Specification:

- Input Voltage: 12VDC
- Stroke Length: 30cm
- Retracted Length: 42cm
- Extended Length: 72cm
- Max Push Load: 1500N
- Travel Speed Without a Load: 5.7 mm/s
- No Load Current: 0.8A
- Max Load Current: 3A

5) Spray Gun with its compressor.

Specifications:

- Input Voltage: $220 - 240V; 50 - 60Hz$
- Power Consumption: 650W
- Container Volume: 800ml
- Hose Length: 1.5m
- Maximum Viscosity: 130 DIN-$Secs$
- Motor Speed: 32,000RPM

- Mass: $1.9 kg$

6) A Relay.

7) 4 Wheels.

Specifications:

- $DIA = 6.8\ cm$
- $Width = 2.6\ cm$
- $weight\ of\ 4\ wheels = 4 * 0.17263kg = 0.69kg$

8) 4 Brushless DC Motors.

Choosing a motor is a compromise between what we want it to do and what is available at a cost we can afford. The intelligent choice of a motor requires us to understand the workings, advantages, and disadvantages of various motor parameters and to develop a specification for the motor performance characteristics.

To begin the basic mobility platform, we need to decide on the overall size. The motors, wheels and batteries constitute most of the robot bulk and weight. To put these units together, we need to scrutinize the contest rules, add in our approach, and derive the platform requirements. The two most basic requirements for robot drive motors are rotation speed (sometimes called angular velocity) and torque.

Specifications:

- Operating Voltage: 3.0-12.0V
- Nominal Voltage: 6
- Speed (No Load): 6200 RPM
- Current (No Load): 0.1A
- Speed (At Maximum Efficiency): 5200 RPM
- Current (At Maximum Efficiency): 0.36A
- Torque: 25 mN.m
- Output Power: 1.84 Watt

9) 3 DC Motor Drivers (L298N)

The L298N is an integrated monolithic circuit in a 15-lead Multiwatt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

3.4.2 Circuit Diagram

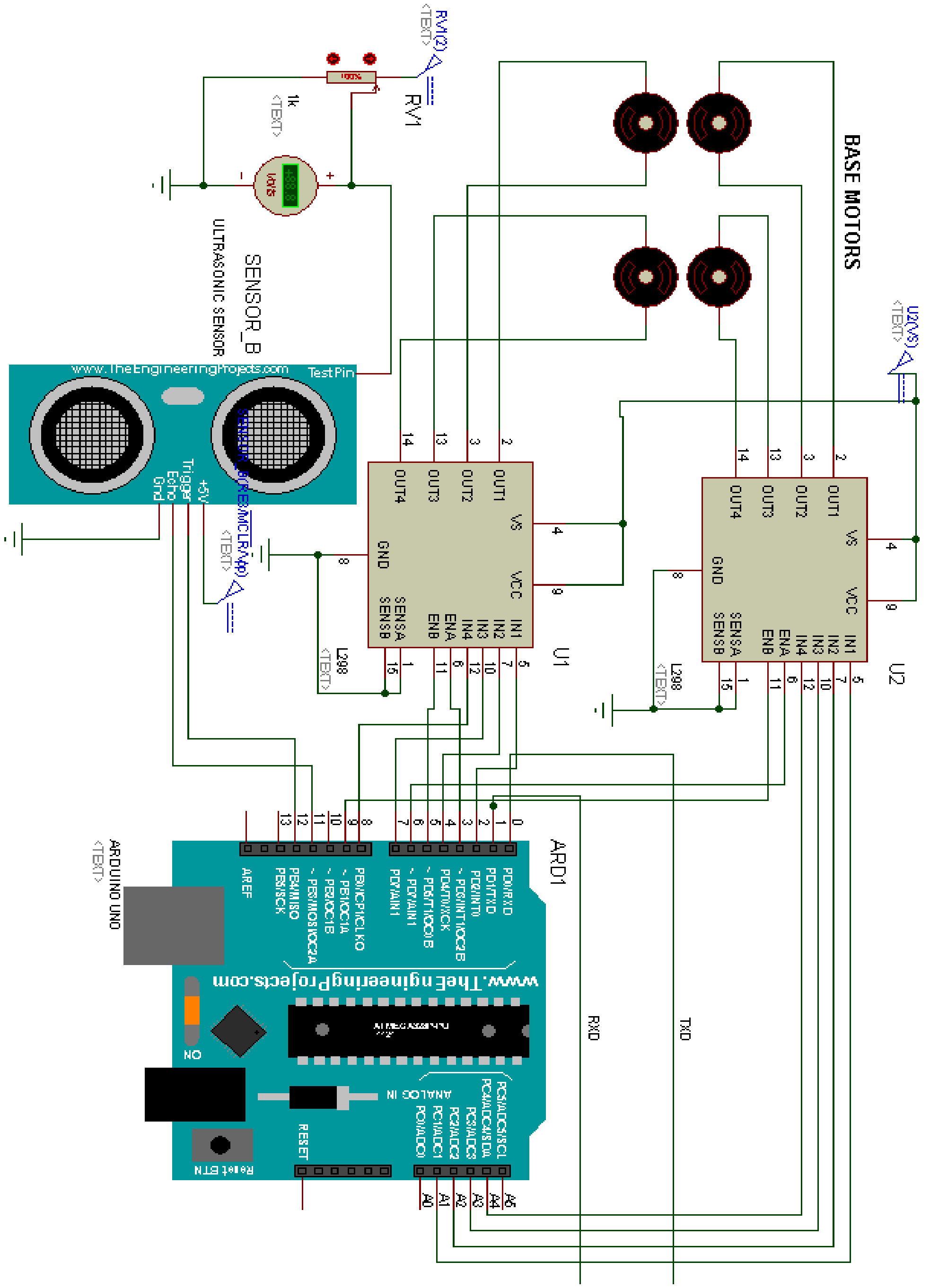

Figure 3-4 Circuit Diagram A

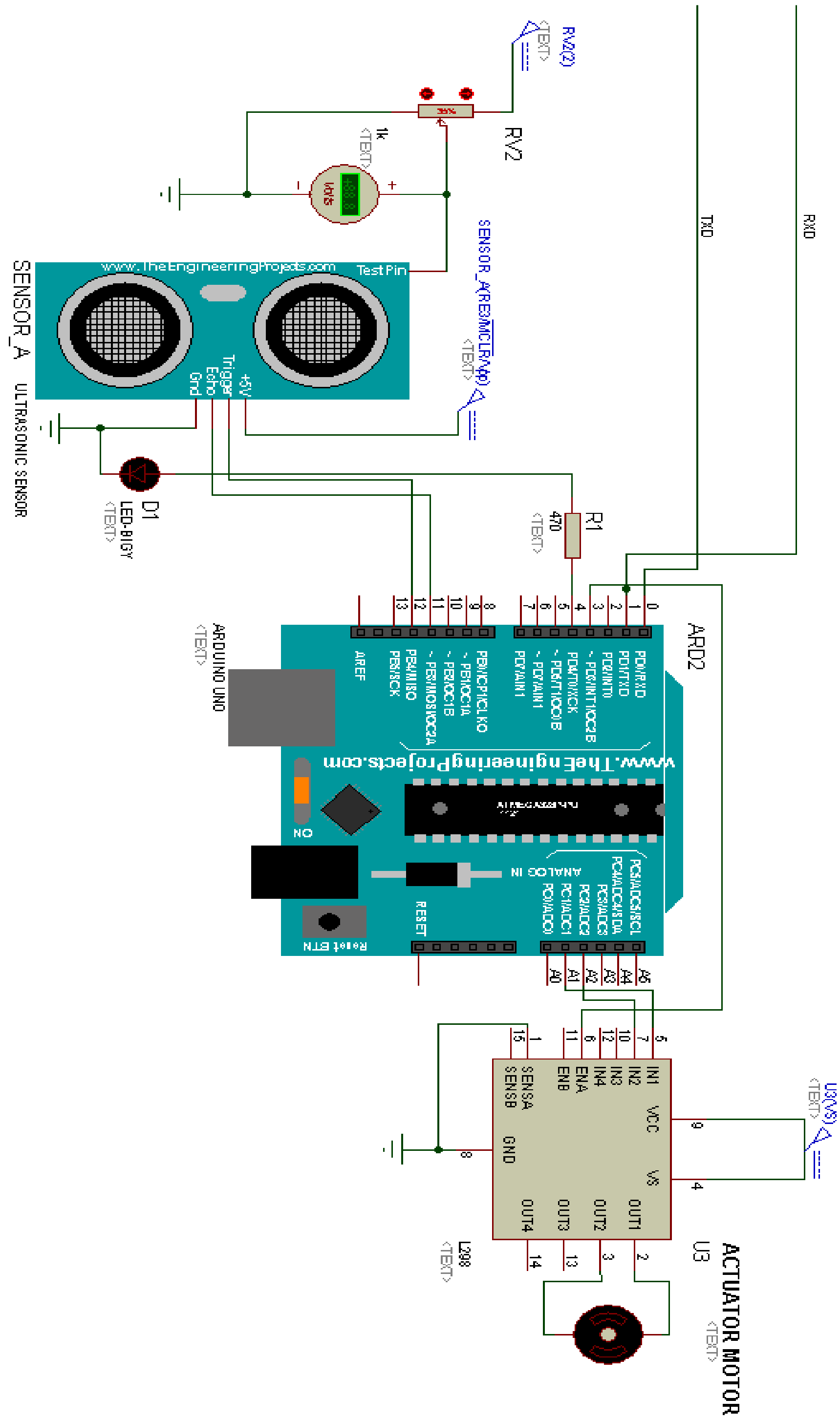

Figure 3-5 Circuit Diagram B

3.5 System Flow Chart

The painting process begins by calibrating the robot either to the left side or to the right side, whichever is closer, after which, turns the spray gun on and moves horizontally to the end of the wall, then moving a step up. Repeating the same pattern (left/right, up a step, left/right) until the a rectangular is painted. Then the painting process finishes with turning the spray gun off and bringing the lift down to its original position.

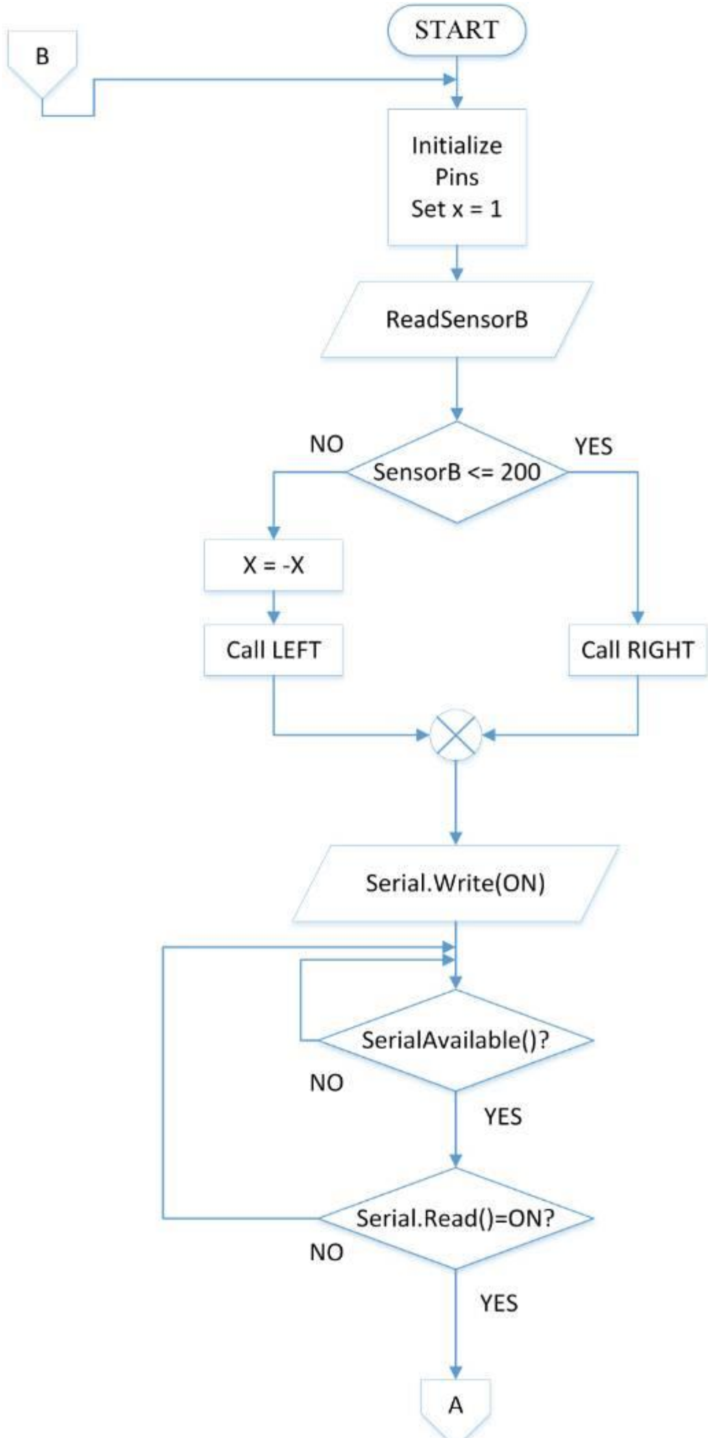

Figure 3-6 Control of The Base Motors According to the First Ultrasonic Sensor (Sensor_A)_1

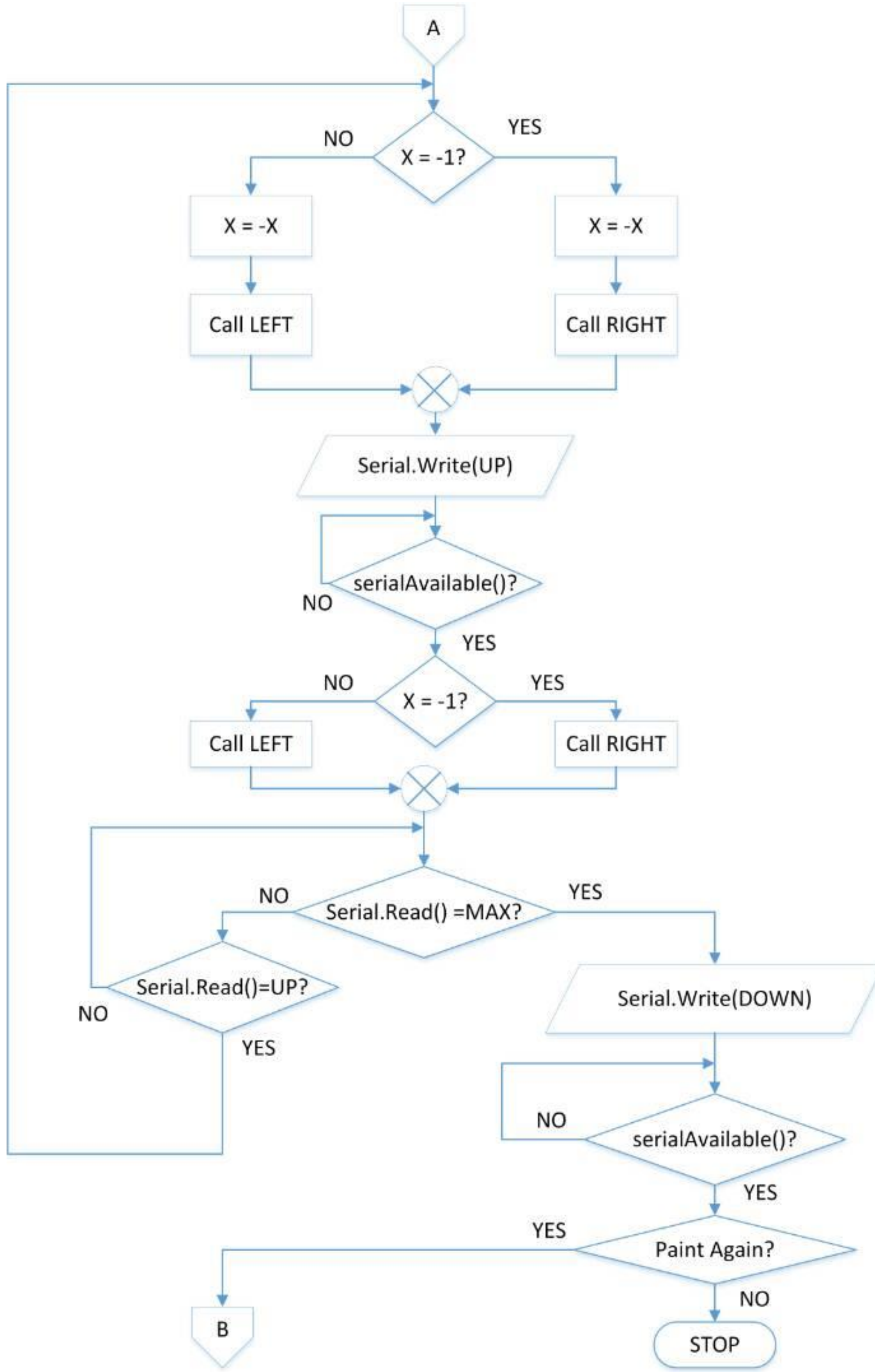

Figure 3-7 Control of The Base Motors According to the First Ultrasonic Sensor (Sensor_A)_2

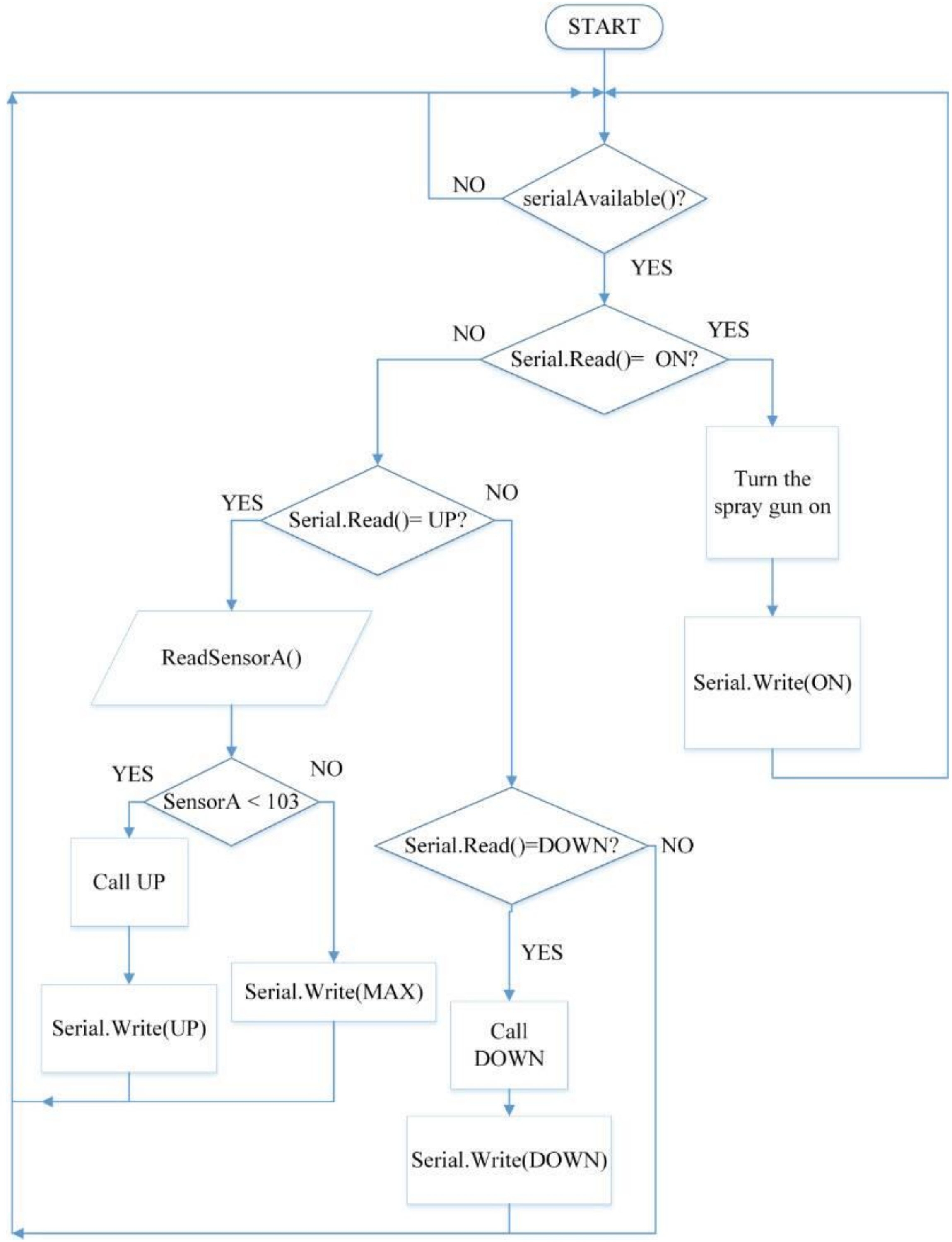

Figure 3-8 Control of The Spray Gun And The Acuator Motor Acoording to The Second Ultrasonic Sensor (Sensor_B)

RIGHT: A user defined function in Arduino1 that signals the 4 DC motors driving the wheels to rotate clockwise, moving the robot to the right, all the while continuously reading the value of SensorB. When the reading of SensorB drops below 10cm Arduino1 signals the motors to halt.

LEFT: A user defined function in Arduino1 that signals the 4 DC motors driving the wheels to rotate counter-clockwise, moving the robot to the left, all the while continuously reading the value of SensorB. When the reading of SensorB rises above 260cm Arduino1 signals the motors to halt.

ONE-STEP-UP: A user defined function in Arduino2, signals the actuator to move forward a horizontal distance of 5cm, which translate to an approximate vertical distance of 17cm. this depends on the reading of SensorA. The function calculates the difference between the sensor's previous reading and the current reading, when this difference reaches 17cm, the Arduino signals the actuator to halt. In case the lift has reached its highest level then Arduino2 send the signal MAX to Arduino1.

ALL-THE-WAY-DOWN: A user defined function in Arduino2, turn the spray gun off first then signals the actuator to move backward a horizontal distance of 30cm, which translate to an approximate vertical distance of 103cm, returning the scissor lift to its original state. this depends on the reading of SensorA. The function continuously reads the value of SensorA, when this value reaches 103cm, the Arduino signals the actuator to halt.

ON, UP, DOWN, MAX, are all assigned to numbers 1,2,3,4 respectively, in both Arduino boards to make the process easier to follow.

3.6 Software Tools

- Proteus Design suite, v7.7 SP2.
- Arduino Environment.
- Microsoft Visio 2016.

CHAPTER FOUR

RESULTS

AND

DISCUSSION

4 CHAPTER FOUR: RESULT AND DICUSSION

4.1 Various Input scenarios

4.1 Various Input scenarios

The table below explains the movement of the robot in accordance to the values of both ultrasonic sensors. Each scenario shows the effect of the different values of SensorB, while SensorA maintains a constant value. The painting process begins and ends with the scissor lift at its lower position.

Table 4-1 Various Input Scenarios

Scenario	**Sensor A value**	**Sensor B value**	**Resulting Movement**		
			Beginning of Painting Process	Middle of Painting Process	End of Painting Process
1.	Min	Left	Turn Spray Gun ON and Moves Right	Moves Right	Halts operation
		Right	Turn Spray Gun ON and Moves Left	Moves Left	Halts operation
		Middle	Calibrate to either Right or Left	Moving to either sides	______________

2.	Middle	Left	—	Moves Right	—
		Right	—	Moves Left	—
		Middle	—	Moving to either side	—
3.	Max	Left	—	Moves Right	Turn Spray Gun OFF and lower lift
		Right	—	Moves Left	Turn Spray Gun OFF and lower lift
		Middle	—	Moving to either sides	—

CHAPTER FIVE

CONCLUSION

AND

RECOMMENDATION

5 CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

5.2 Recommendations

5.1 Conclusion

A prototype that paints an area of $3.14m^2$ was designed. The approach uses 2 ultrasonic sensors to measure distance and provide feedback to the Arduino boards which in turn controls the base wheels and the actuator.

The prototype was designed for the purpose of automating the interior walls painting process, making it easier and more efficient. This design is simple in nature and relatively easy to implement in comparison with the reminder of interior wall painting robots. Adding to that, the stability of its structure, and the fact that it can be built using any other material, judging by its availability, affordability and in accordance to the needed specifications.

A full-scale interior wall painting robot based on this prototype would be beneficial to the construction field corporations, granting these corporations the ability to provide painting services in addition to the actual construction work, which gives an advantage over other painting and construction corporations, while maintaining a reasonable spending ceil on acquiring the robot and/or building it.

5.2 Recommendations

For future work we recommend the following:

- Using multiplexers to reduce the number of arduinos in the circuit.
- Implementing the final product using microcontrollers from the AVR series instead of Arduino board environment.

- Increase the number of sensors to cover more work area.
- Adding a Z-axis movement, gives the capability to paint a 4-walled room with no human interference.
- Increasing its degrees of freedom to include yaw, pitch and roll to reach the edges and margins of the wall to be painted and the ceiling.
- Utilize a liquid level sensor to halt the operation when the paint runs out. And a pressure sensor on the nozzle to alert if the nozzle is blocked by previous dry paint.
- Exploit external mix nozzles instead of a spray gun.
- Employ omni-wheels.

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A. APPENDIX A

SYSTEM'S CODE

ARDUINO1'S CODE:

```
#define IN11 2
#define IN12 4
#define IN13 7
#define IN14 8
#define PWM1A 3
#define PWM1B 5
#define IN21 A1
#define IN22 A2
#define IN23 A3
#define IN24 A4
#define PWM2A 6
#define PWM2B 9
#define ECHO 11
```

```
#define TRIG 12

long duration,cm;

int Mspeed = 50;

#define ON 1

#define DONE_UP 2

#define UP 3

#define DOWN 4

#define MAX 5

#define FINISHED 6

int cal=0;

int x=1;

int y;


void setup() {

  Serial.begin(9600);

  pinMode(TRIG, OUTPUT);
```

```
pinMode(ECHO,INPUT);

pinMode(IN11,OUTPUT);

pinMode(IN12,OUTPUT);

pinMode(IN13,OUTPUT);

pinMode(IN14,OUTPUT);

pinMode(PWM1A,OUTPUT);

pinMode(PWM1B,OUTPUT);

pinMode(IN21,OUTPUT);

pinMode(IN22,OUTPUT);

pinMode(IN23,OUTPUT);

pinMode(IN24,OUTPUT);

pinMode(PWM2A,OUTPUT);

pinMode(PWM2B,OUTPUT);

if(cal==0)

 Calibrate();

cal++;
```

```
}

void loop() {

  while(Serial.available())
  {
      y= Serial.read();
    switch (y)
    {
      case DONE_UP:
      Serial.println("Raised 17cm");
      switch (x)
        {
    case -1:
    LEFT();
    x=-x;
```

```
break;
case 1:
RIGHT();
x=-x;
break;
    }
    Serial.println("UP");
    Serial.write(UP);
  break;
  case MAX:
  Serial.println("MAXIMUM height is reached");
   switch (x)
    {
case -1:
LEFT();
x=-x;
```

```
break;
case 1:
RIGHT();
x=-x;
break;
    }
 Serial.println("Lower the lift and turn the spray gun OFF");
 Serial.write(DOWN);
  break;
  case FINISHED:
  Serial.println("DO YOU WANT TO PAINT AGAIN (Y/N)");
  break;
}
}
}
```

```
void Calibrate(){

  cm=ReadSensorB();

if(cm>=105 && cm<260)

   {

  Serial.print(cm);

  Serial.println(" cm");

  Serial.println(" calibrate to the LEFT");

  LEFT();

  x=-x;

   }

else if(cm<105 && cm>=10)

   {

  Serial.print(cm);

  Serial.println(" cm");

  Serial.println(" calibrate to the RIGHT");

  RIGHT();
```

```
  }
 Serial.write(ON);

 while(!Serial.available())
 { }
  Serial.println("NOZZLE ON");
  delay(200);
  Serial.println("UP");
 Serial.write(UP);

  return;
}

void RIGHT(){
 while(cm>10)
 {
```

```
digitalWrite(IN11,HIGH);

digitalWrite(IN12,LOW);

digitalWrite(IN13,HIGH);

digitalWrite(IN14,LOW);

digitalWrite(IN21,HIGH);

digitalWrite(IN22,LOW);

digitalWrite(IN23,HIGH);

digitalWrite(IN24,LOW);

analogWrite(PWM1A,Mspeed);

analogWrite(PWM1B,Mspeed);

analogWrite(PWM2A,Mspeed);

analogWrite(PWM2B,Mspeed);

cm = ReadSensorB();

  Serial.print(cm);

  Serial.println(" cm");

}
```

```
 digitalWrite(IN11,HIGH);
 digitalWrite(IN12,HIGH);
 digitalWrite(IN13,HIGH);
 digitalWrite(IN14,HIGH);
 digitalWrite(IN21,HIGH);
 digitalWrite(IN22,HIGH);
 digitalWrite(IN23,HIGH);
 digitalWrite(IN24,HIGH);
 analogWrite(PWM1A,Mspeed);
 analogWrite(PWM1B,Mspeed);
 analogWrite(PWM2A,Mspeed);
 analogWrite(PWM2B,Mspeed);
  delay(100);
  return;
}
```

```
void LEFT(){
 while(cm<260)
 {
 digitalWrite(IN11,LOW);
 digitalWrite(IN12,HIGH);
 digitalWrite(IN13,LOW);
 digitalWrite(IN14,HIGH);
 digitalWrite(IN21,LOW);
 digitalWrite(IN22,HIGH);
 digitalWrite(IN23,LOW);
 digitalWrite(IN24,HIGH);
 analogWrite(PWM1A,Mspeed);
 analogWrite(PWM1B,Mspeed);
 analogWrite(PWM2A,Mspeed);
 analogWrite(PWM2B,Mspeed);
 cm = ReadSensorB();
```

```
Serial.print(cm);
Serial.println(" cm");
}
digitalWrite(IN11,HIGH);
digitalWrite(IN12,HIGH);
digitalWrite(IN13,HIGH);
digitalWrite(IN14,HIGH);
digitalWrite(IN21,HIGH);
digitalWrite(IN22,HIGH);
digitalWrite(IN23,HIGH);
digitalWrite(IN24,HIGH);
analogWrite(PWM1A,Mspeed);
analogWrite(PWM1B,Mspeed);
analogWrite(PWM2A,Mspeed);
analogWrite(PWM2B,Mspeed);
delay(100);
```

```
  return;
 }
long ReadSensorB(){
digitalWrite(TRIG,LOW);
delayMicroseconds(2);
digitalWrite(TRIG,HIGH);
delayMicroseconds(10);
digitalWrite(TRIG,LOW);
duration = pulseIn(ECHO,HIGH);
cm= msec_to_cm(duration);
return cm;
}
long msec_to_cm(long msec)
{
 // The speed of sound is 340 m/s or 29 microseconds per centimeter.
 // The ping travels out and back, so to find the distance of the
```

```
  // object we take half of the distance travelled.
  return msec / 29 / 2;
}
```

Arduino2's Code:

```
#define IN1 A1

#define IN2 A2

#define PWMA 3

#define TRIG 12

#define ECHO 11

#define ON 1

#define DONE_UP 2

#define UP 3

#define DOWN 4

#define MAX 5

#define FINISHED 6

#define NOZZLE 4

int y;

long initial;

long previous=0;
```

```
long displacement;
int Mspeed = 50;
long duration, cm;
void setup() {
  pinMode(IN1,OUTPUT);
  pinMode(IN2,OUTPUT);
  pinMode(PWMA,OUTPUT);
  pinMode(TRIG,OUTPUT);
  pinMode(ECHO,INPUT);
  pinMode(NOZZLE,OUTPUT);
  Serial.begin(9600);
  initial=ReadSensorA();
  displacement= 103.92-initial;
}
void loop() {
  while(Serial.available())
```

```
  {
   y= Serial.read();
   switch (y)
   {
    case ON:
   TURN_ON();
   break;
    case UP:
    ONE_STEP_UP();
    break;
    case DOWN:
    ALL_THE_WAY_DOWN();
   }
  }
}
```

```
void ONE_STEP_UP(){
  cm = ReadSensorA();
  Serial.print(cm);
  Serial.println(" cm");
  if (cm >= 103)
  {
  Serial.println("MAX");
  Serial.write(MAX);
  }
  else if(cm < 103)
  { previous = cm;
  while(abs(previous - cm) < 17 || cm ==103)
   {
  digitalWrite(IN1,HIGH);
  digitalWrite(IN2,LOW);
  analogWrite(PWMA,Mspeed);
```

```
  cm = ReadSensorA();
   Serial.print("now ");
  Serial.print(cm);
  Serial.println(" cm");
  Serial.print("was ");
   Serial.print(previous);
  Serial.println(" cm");
   }
   digitalWrite(IN1,HIGH);
   digitalWrite(IN2,HIGH);
  Serial.println("DONE_UP");
  Serial.write(DONE_UP);
  return;
  }
}
void TURN_ON()
```

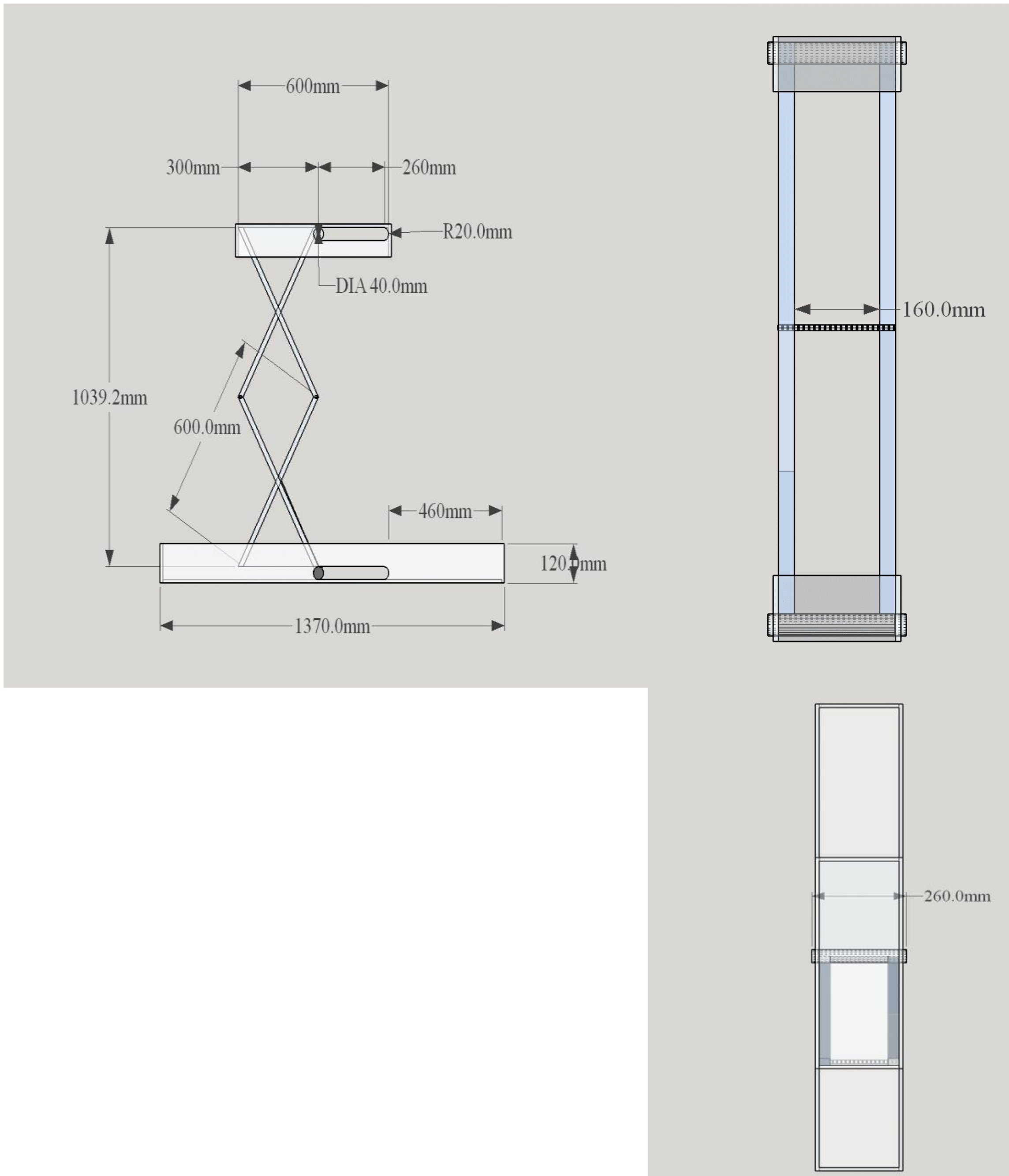
```
{
  digitalWrite(NOZZLE,HIGH);
  Serial.println("NOZZLE ON");
Serial.write(ON);
  return;
}

void ALL_THE_WAY_DOWN()
{
  while(cm != 4)
  {
   digitalWrite(IN1,LOW);
   digitalWrite(IN2,HIGH);
   analogWrite(PWMA,Mspeed);
   cm = ReadSensorA();
   Serial.print(cm);
```

```
 Serial.println(" cm");
 }
  digitalWrite(IN1,HIGH);
  digitalWrite(IN2,HIGH);
  Serial.println("The Lift is lowered");
  digitalWrite(NOZZLE,LOW);
  Serial.println("Spray gun turned OFF");
  Serial.write(FINISHED);
  return;
}

long ReadSensorA(){
digitalWrite(TRIG,LOW);
delayMicroseconds(2);
digitalWrite(TRIG,HIGH);
delayMicroseconds(10);
```

```
digitalWrite(TRIG,LOW);

duration = pulseIn(ECHO,HIGH);

cm= msec_to_cm(duration);

return cm;

}

long msec_to_cm(long msec)

{

  // The speed of sound is 340 m/s or 29 microseconds per centimeter.

  // The ping travels out and back, so to find the distance of the

  // object we take half of the distance travelled.

  return msec / 29 / 2; }
```

B. APPENDIX B

SCHEMATICS OF SCISSOR LIFT SPECIFICATIONS



600mm
300mm
260mm
R20.0mm
DIA 40.0mm
1039.2mm
600.0mm
460mm
120.0mm
1370.0mm
160.0mm
260.0mm